

What is Claimed Is:

- 1 1. A method for decomposition of projection data acquired by scanning a set of objects
2 using at least two x-ray spectra, the projection data including low energy projections (P_L) and
3 high energy projections (P_H), said method comprising:
 - 4 A. solving the projections P_L and P_H to determine a photoelectric line integral (A_p)
5 component of attenuation and a Compton line integral (A_c) component of
6 attenuation of the set of scanned objects using multi-step fitting; and
7 B. reconstructing a Compton image I_c and a photoelectric image I_p from A_c and A_p .
- 1 2. The method of claim 1, further including, prior to step A, performing a calibration
2 procedure using simulated data or measured data or some combination of simulated and
3 measured data.
- 1 3. The method of claim 1, further including, prior to step A, performing a calibration
2 procedure, wherein said calibration procedure includes generating low energy iso-transmission
3 contours for known values of P_L at known values of A_p and at known values of A_c .
- 1 4. The method of claim 3, wherein said calibration procedure includes, for each of said low
2 energy iso-transmission contours, fitting A_p to a polynomial function $g_L(A_c)$, wherein g_L is a
3 polynomial function that represents the shape of the contour.
- 1 5. The method of claim 4, wherein g_L includes a set of coefficients g_{Li} determined at said
2 known values of P_L and said calibration procedure includes fitting the values of each coefficient
3 g_{Li} to a polynomial function $h_{Li}(P_L)$.
- 1 6. The method of claim 1, wherein said calibration procedure includes computing minimum
2 and maximum values of P_H for each of said low-energy iso-transmission contours as a function
3 of P_L .

- 1 7. The method of claim 6, wherein said calibration procedure includes fitting the minimum
2 values of P_H to a polynomial function $m_L(P_L)$.
- 1 8. The method of claim 6, wherein said calibration procedure includes fitting the maximum
2 values of P_H to a polynomial function $n_L(P_L)$.
- 1 9. The method of claim 1, wherein said calibration procedure includes generating high
2 energy iso-transmission contours for known values of P_H at known values of the A_p and at known
3 values of the A_c .
- 1 10. The method of claim 9, wherein said calibration procedure includes, for each of said high
2 energy iso-transmission contours, fitting A_p to a polynomial function $g_H(A_c)$, wherein g_H is a
3 polynomial function that represents the shape of the contour for a given P_H .
- 1 11. The method of claim 10, wherein said g_H includes a set of coefficient g_{Hi} determined at
2 said known values of P_H and said calibration procedure includes fitting the values of each
3 coefficient g_{Hi} to a polynomial function $h_{Hi}(P_H)$.
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- 5 12. The method of claim 1, wherein step A includes generating a low energy iso-transmission
6 contour corresponding to P_L and a high energy iso-transmission contour corresponding to P_H .
- 1 13. The method of claim 12, wherein step A includes determining the values of the A_p and A_c
2 at the intersection of said low energy iso-transmission contour and the high energy iso-
3 transmission contour.
- 1 14. The method of claim 13, wherein the intersection of the low energy iso-transmission
2 contour and the high energy iso-transmission contour is determined by equating a first
3 polynomial function $g_L(A_c)$ representing said low energy iso-transmission contour, wherein g_L is
4 a polynomial function that represents the shape of the contour of P_L , with a second polynomial

5 function $g_H(A_c)$ representing said high energy iso-transmission contour, wherein g_H is a
6 polynomial function that represents the shape of the contour for a given P_H .

1 15. The method of claim 12, further including computing a modified value of the input low
2 energy projection data (P_{Lc}) and a modified value of the input high energy projection data (P_{Hc}),
3 wherein each of said modified values P_{Lc} and P_{Hc} are clamped to be bounded between two
4 values.

1 16. The method of claim 15, including representing the low energy iso-transmission contour
2 with a polynomial function g_L and determining a set of coefficients of g_L as a function of P_{Lc} .

1 17. The method of claim 15, including representing the high energy iso-transmission contour
2 with a polynomial function g_H and determining a set of coefficients of g_H as a function of P_{Hc} .

1 18. The method of claim 15, further including, prior to step A, generating calibration data
2 using P_L , wherein P_{Lc} is computed by clamping the value of P_L to lie between 0 and the
3 maximum value of P_L used to generate said calibration data.

1 19. The method of claim 15, wherein the modified value P_{Hc} is determined by clamping the
2 value of P_H to lie between a minimum value of P_H (P_{Hmin}) and a maximum value of P_H (P_{Hmax}).

1 20. The method of claim 19, including determining P_{Hmin} as a function of P_{Lc} and a
2 polynomial function n_L and determining P_{Hmax} as a function of P_{Lc} and a polynomial function m_L ,
3 wherein m_L is a polynomial function that determines P_{Hmin} for a given value of P_{Lc} and wherein
4 n_L is a polynomial function that determines P_{Hmax} for a given value of P_{Lc} .

1 21. The method of claim 1, wherein step A includes calculating a scaled Compton line
2 integral value (A_{cs}) as a function of a scale factor s_c and A_c and calculating a scaled photoelectric
3 line integral value (A_{ps}) as a function of a scale factor s_p and A_{ps} .

1 22. The method of claim 21, wherein step B includes constructing said I_c and said I_p as a
2 function of said A_{cs} and said A_{ps} .

1 23. The method of claim 1, further including, after step B, determining an image of a basis
2 function $X(I_X)$ and a basis function $Y(I_Y)$, by solving I_c and I_p on a pixel-by-pixel basis, wherein
3 the basis functions $X(I_X)$ and $Y(I_Y)$ are functions linearly combined to determine the pixel
4 intensities in I_c and I_p .

1 24. A method for decomposition of projection data acquired by scanning a set of objects
2 using at least two x-ray spectra, said projection data including low energy projection data (P_L)
3 and high energy projection data (P_H), said method comprising:

4 A. performing a calibration procedure using at least some simulated data or
5 measured data or a combination of simulated and measured data, including:

6 i. generating low energy iso-transmission contours for known values of P_L
7 and high energy iso-transmission contours for known values of P_H ;

8 ii. generating a polynomial g_L that represents the shape of the low energy iso-
9 transmission contour for each P_L , wherein g_L includes a set of coefficients
10 g_{Li} determined at said known values of P_L ;

11 iii. generating a polynomial g_H that represents the shape of the high energy
12 iso-transmission contour for each P_H , wherein g_H includes a set of
13 coefficients g_{Hi} determined at said known values of P_H ;

14 iv. generating polynomials h_L that represents the variation of the coefficients
15 of the polynomial g_L as a function of P_L ;

16 v. generating polynomials h_H that represents the variation of the coefficients
17 of the polynomial g_H as a function of P_H ;

18 vi. determining the minimum and maximum values of P_H for each
19 transmission line corresponding each P_L ;

20 vii. generating a polynomial m_H that represents the variation of the minimum

- 21 value of P_H as a function of P_L ; and
- 22 viii. generating a polynomial n_H that represents the variation of the maximum
- 23 value of P_H as a function of P_L ;
- 24 B. solving the projections P_L and P_H to determine a photoelectric line integral (A_p)
- 25 component of attenuation and a Compton line integral (A_c) component of
- 26 attenuation of the set of scanned objects using a multi-step fitting procedure,
- 27 including:
- 28 i. computing the values of each coefficient g_{Li} using a polynomial function
- 29 $h_{Li}(P_L)$ and computing the values of each coefficient g_{Hi} using a
- 30 polynomial function $h_{Hi}(P_H)$; and
- 31 ii. determining A_c and A_p as a function of P_L and P_H , using the coefficients of
- 32 g_L and the coefficients of g_H ; and
- 33 C. reconstructing a Compton image I_c and a photoelectric image I_p from A_c and A_p .
- 1 25. The method of claim 24, further including, after step C, determining an image of a basis
- 2 function $X(I_X)$ and a basis function $Y(I_Y)$, by solving image I_c and image I_p on a pixel-by-
- 3 pixel basis.
- 1 26. A system for decomposing projection data for a set of scanned objects acquired using at
- 2 least two x-ray spectra, said system comprising:
- 3 A. media for storing low energy projection data (P_L) and high energy projection data
- 4 (P_H);
- 5 B. a decomposition module configured to determine a photoelectric line integral (A_p)
- 6 component of attenuation and a Compton line integral (A_c) component of
- 7 attenuation for P_L and P_H using multi-step fitting; and
- 8 C. an image construction module configured to construct a Compton image (I_c) and a
- 9 photoelectric image (I_p) from the A_p and A_c .
- 1 27. The system of claim 26, wherein the decomposition module includes:

2 D. a calibration module configured to calibrate the decomposition module using at
3 least some simulated data or measured data or a combination of simulated data
4 and measured data.

1 28. The system of claim 27, wherein the calibration module is configured to generate low
2 energy iso-transmission contours for known values of P_L at known values of A_p and at known
3 values of A_c .

1 29. The system of claim 28, wherein the calibration module is configured, for each of said
2 low energy iso-transmission contours, to fit A_p to a polynomial function $g_L(A_c)$, wherein g_L is a
3 polynomial function that represents the shape of the contour.

1 30. The system of claim 29, wherein g_L includes a set of coefficients g_{Li} determined at said
2 known values of P_L and the calibration module is configured to fit said set of coefficients g_{Li} to a
3 polynomial function $h_{Li}(P_L)$.

4 31. The system of claim 28, wherein the calibration module is configured to compute the
5 minimum and maximum values of P_H for each of the low-energy iso-transmission contours
6 corresponding to P_L .

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1 32. The system of claim 28, wherein the calibration module is configured to fit the minimum
2 values of P_H to a polynomial function $m_L(P_L)$.

1 33. The system of claim 28, wherein the calibration module is configured to fit the maximum
2 values of P_H to a polynomial function $n_L(P_L)$.

1 34. The system of claim 27, wherein the calibration module is configured to generate high
2 energy iso-transmission contours for known values of P_H at known values of A_p and at known
3 values of A_c .

- 1 35. The system of claim 34, wherein the calibration module is configured, for each of said
2 high energy iso-transmission contours, to fit A_p to a polynomial function of $g_H(A_c)$, wherein g_H is
3 a polynomial function that represents the shape of the contour for a given P_H .
- 1 36. The system of claim 34, wherein g_H includes a set of coefficients g_{Hi} determined at said
2 known values of P_H and the calibration module is configured to fit said set of coefficients g_{Hi} to a
3 polynomial function $h_{Hi}(P_H)$.
- 1 37. The system of claim 26, wherein the decomposition module is configured to generate a
2 low energy iso-transmission contour corresponding to P_L and a high energy iso-transmission
3 contour corresponding to P_H .
- 1 38. The system of claim 37, wherein the decomposition module is configured to determine
2 the values of A_p and A_c at the intersection of said low energy iso-transmission contour and the
3 high energy iso-transmission contour.
- 1 39. The method of claim 37, wherein the decomposition module is configured to compute a
2 modified value of the input low energy projection data (P_{Lc}) and a modified value of the input
3 high energy projection data (P_{Hc}), and configured to clamp said modified values P_{Lc} and P_{Hc}
4 between two values.
- 1 40. The system of claim 39, wherein the decomposition module is configured to clamp the
2 values of P_L to lie between 0 and the maximum value of P_L used to generate a set of calibration
3 data and to compute the modified value P_{Lc} as a function of the clamped values of P_L .
- 1 41. The system of claim 39, wherein the decomposition module is configured to clamp P_{Hc}
2 between a minimum value of P_H (P_{Hmin}) and a maximum value of P_H (P_{Hmax}).

1 42. The system of claim 43, wherein the decomposition module is configured to determine
2 P_{Hmin} as a function of P_{Lc} and a polynomial n_L and to determine P_{Hmax} as a function of P_{Lc} and a
3 polynomial m_L , wherein m_L is a polynomial function representing the coefficients of P_L for the
4 minimum values of P_H and wherein n_L is a polynomial function representing the coefficients of
5 P_L for the maximum values of P_H .

1 43. The system of claim 26, wherein the decomposition module is configured to calculate a
2 scaled Compton line integral value (A_{cs}) as a function of a scale factor s_c and A_c and to calculate a
3 scaled photoelectric line integral value (A_{ps}) as a function of a scale factor s_p and A_{ps} .

1 44. The system of claim 45, wherein the image reconstruction module is configured to
2 reconstruct said I_c and said I_p as a function of said A_{cs} and said A_{ps} .

1 45. The system of claim 26, wherein the image reconstruction module is configured to
2 determine an image of a basis function $X(I_X)$ and of a basis function $Y(I_Y)$, by solving I_c and I_p
3 on a pixel-by-pixel basis, wherein the basis functions $X(I_X)$ and $Y(I_Y)$ are functions linearly
4 combined to determine the pixel intensities in I_c and I_p .

1 46. A system for decomposing projection data for a set of scanned objects acquired using at
2 least two x-ray spectra, said system comprising:

- 3 A. media for storing low energy projection data (P_L) and high energy projection data
4 (P_H);
- 5 B. a calibration module configured to calibrate the decomposition module using at
6 least some simulated data or measured data or a combination of simulated and
7 measured data, and configured to:
 - 8 i. generate a low energy iso-transmission contour corresponding to P_L and a
9 high energy iso-transmission contour corresponding to P_H ;
 - 10 ii. generate a polynomial g_L that represents the shape of the low energy iso-
11 transmission contour, wherein g_L includes a set of coefficients g_{Li}

- 12 determined at said known values of P_L ;
- 13 iii. generate a polynomial g_H that represents the shape of the high energy iso-
- 14 transmission contour, wherein g_H includes a set of coefficients g_{Hi}
- 15 determined at said known values of P_H ;
- 16 iv. generate polynomials h_L that represents the variation of the coefficients of
- 17 the polynomial g_L as a function of P_L ;
- 18 v. generate polynomials h_H that represents the variation of the coefficients of
- 19 the polynomial g_H as a function of P_H ;
- 20 vi. determine the minimum and maximum values of P_H for each transmission
- 21 line corresponding each P_L ;
- 22 vii. generate a polynomial m_H that represents the variation of the minimum
- 23 value of P_H as a function of P_L ; and
- 24 viii. generate a polynomial n_H that represents the variation of the maximum
- 25 value of P_H as a function of P_L ;
- 26 C. a decomposition module configured to determine a photoelectric line integral (A_p)
- 27 component of attenuation and a Compton line integral (A_c) component of
- 28 attenuation for P_L and P_H using multi-step fitting, and configured to:
- 29 i. compute the values of each coefficient g_{Li} using a polynomial function
- 30 $h_{Li}(P_L)$ and to compute the values of each coefficient g_{Hi} using a
- 31 polynomial function $h_{Hi}(P_H)$; and
- 32 ii. determine A_c and A_p as a function of P_L and P_H using the coefficients of g_L
- 33 and the coefficients of g_H ; and
- 34 D. an image reconstruction module configured to reconstruct a Compton image (I_c)
- 35 and a photoelectric image (I_p) from the A_p and A_c .

1 47. The system of claim 46, wherein the image construction module is configured to

2 determine an image of a basis function $X(I_X)$ and of a basis function $Y(I_Y)$, by solving image I_c

3 and image I_p on a pixel-by-pixel basis.